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NATO-CCMS Pilot Study on Disposal of Hazardous Wastes. Project: Landfill Research Project Leader: Canada

NATO Committee on the Challenges of Modern Society, Brussels (Belgium)

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Report is a combination and up-date of the landfill subproject completed in 1977 as part of first phase of Pilot Study on Disposal of Hazardous Waste, NATO/CCMS Report No. 64. It focuses on the following areas which reflect main landfill areas being investigated: (1) research conducted on co-disposal, (2) contaminant migration and attenuation, (3) waste isolation, (4) waste immobilization, (5) landfill procedures, (6) long-term effect, (7) leachate treatment, and (8) national guidelines and/or regulations.

KEYWORDS: *Hazardous materials, *Solid waste disposal, *Earth fills, *Foreign technology.

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COMMITTEE ON

THE CHALLENGES OF

MODERN SOCIETY

DISPOSAL OF HAZARDOUS WASTES

LANDFILL RESEARCH

Number 120

NORTH ATLANTIC TREATY ORGANIZATION

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NATO CCMS Pilot Study "Disposal of Hazardous Wastes"

Project: Landfill Research

Project Leader: Canada

F i n a l R e p o r t

February 16, 1981

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1 SUMMARY AND RECOMMENDATIONS

1.1 Summary of Sub-Project

Phase I and Phase II research and practical experience seems to indicate that hazardous wastes landfilling is technically feasible without serious immediate or medium-term environmental impact provided that sites are properly located, that proper controls are implemented, that proper operations are followed, that contingency planning is undertaken, and that adequate maintenance and monitoring procedures are undertaken.

1.2 Recommendations of Sub-Project

Further research mostly on the long-term environmental impact and other implications of hazardous waste landfilling must be undertaken as a continuation of this sub-project as outlined in Section 6.

2 INTRODUCTION

2.1 Project Description

The objective of the phase 2 Landfill Research Sub-project is to continue with the assessment of the contribution that landfilling and "special chemical landfilling" can make towards an environmentally acceptable disposal of hazardous wastes with emphasis on the principle that sophisticated and energy costly treatment is not always necessary and can quite often be avoided for instance in the case of low toxicity industrial wastes if their long-term behaviour can be predicted.

It should be indeed stressed that the disposal of hazardous wastes in landfills can be an environmentally acceptable method, provides long-term effects and behaviour of these wastes are taken into account.

This report is then, in short, a continuation and up-date of the landfill sub-project which was completed in 1977 as part of the first phase of the Pilot Study on the Disposal of Hazardous Wastes, NATO/CCMS Report No. 64. It focuses on the following specific areas of discussion which reflect main landfill areas being investigated by the participants:

- research conducted on co-disposal
- contaminant migration and attenuation
- waste isolation
- waste immobilization
- landfill procedures
- long-term effects
- leachate treatment
- national guidelines and/or regulations

2.2 Participants

The following countries are participating in this project: United States, United Kingdom, Netherlands, Federal Republic of Germany, France, Norway and Canada which is also project leader for this report. This means that all landfill research results were submitted to the project leader so as to be compiled and summarized into a final consistent document.

2.3 Background

The Phase I report, entitled "Disposal of Hazardous Wastes: Landfill" was completed in May 1977 by the United Kingdom (publication number 64). Since at that time much research was still ongoing or planned, an agreement was reached to continue into Phase 2, with emphasis on the technical aspects of landfilling.

2.4 Events

Meetings were held in Munich (Sept. 26-29, 1978) in Vancouver (June 5-8, 1979) and in Angers (October 15-19, 1979) one experts meeting was held in Amersfoort (March 13-15, 1979).

2.5 Structure of Report

It should be underlined that this sub-project is strictly based on information which was made available and that it is basically an effort to summarize the results of several pertinent research studies done by the participating countries in accordance with the topics or areas outlined in 2.1.

In Section 3, the role played by landfilling in a complete hazardous waste management system is examined in general terms in accordance with the waste management system scenario presented in the Phase I NATO/CCMS Report number 62 (Recommended Procedures).

In Section 4, the studies and the findings submitted by the participants on which this sub-report is based, are technically reviewed and summarized.

In Section 5, the potential criteria resulting from this review/research and which may be used as a basis for further guideline or regulation development by regulatory agencies, are identified in general terms.

In Section 6 some future research requirements as identified in the received submissions, are discussed again in general terms.

In Section 7 some basic conclusions are made.

In Section 8 the recommendations for further research are emphasized.

3 LANDFILLING HAZARDOUS WASTES

3.1 Overview

An integrated hazardous waste management program, as recommended by the Sub-Project on Recommended Procedures in NATO/CCMS report number 62, lists steps which should be undertaken to achieve an environmentally acceptable management of hazardous wastes. These steps, in order, are:

1. reduce wastes at source;
2. recover and reuse wastes;
3. incinerate combustible wastes (with provision for energy recovery);
4. detoxify and neutralize remaining wastes; and,
5. land disposal.

(refer to Exhibit 1, page 7, Report No. 62).

It should be noted in this regard that a landfill is an integral part of a management system, as a repository for certain types of wastes and treatment residues.

A diagram (Figure 1) shows material flows associated with a landfilling operation, providing indication of: landfilling alternatives; environmental concerns; environmental controls which can be implemented; and, potential areas requiring regulation and/or guideline development.

3.2 Potential Environmental Concerns

The following concerns were identified by the participants:

- landfill leachate discharge to surface and/or groundwater
- landfill leachate discharge to land
- gas production and migration from hazardous waste co-disposal sites
- orization of liquid organic wastes with release through landfill cover material
- spontaneous combustion and/or other synergistic effects within the landfill.

3.3 Engineered Environmental Controls

Possibilities of implementing the following controls were considered:

(a) leachate control systems, including surface sealing, collection and/or recirculation, treatment, and spray irrigation systems;

(b) gas control systems, including peripheral venting and central extraction systems.

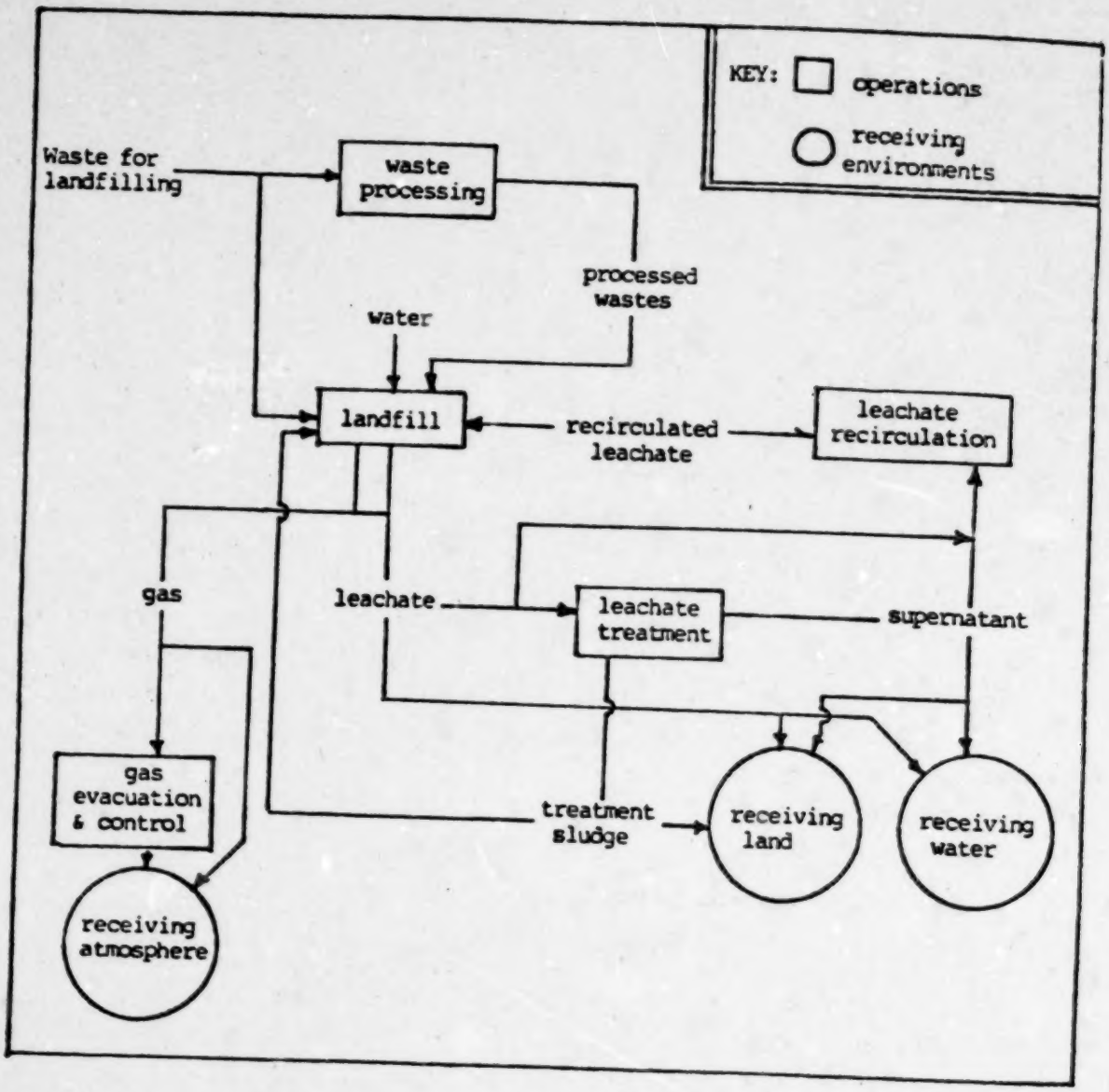

FIGURE 1 MATERIAL FLOWS ASSOCIATED WITH A WASTE LANDFILLING OPERATION

(c) waste disposal systems, including the absorption of liquid wastes into the bulk waste.

3.4 Possible Approaches to Environmentally Acceptable Landfilling

- some wastes may be co-disposed with municipal solids wastes or any other organic wastes, while others of a more hazardous nature may need to be discharged to a special "chemical landfill", or kept in storage until feasible disposal technology becomes available
- waste disposal sites may be constructed as "containment" or "controlled release" sites
- "containment sites" will generally need to be lined with an impermeable natural or synthetic lining material, and provided with a means for leachate collection and treatment (disposal of treatment sludge may become problem)
- "controlled release" sites, which incidentally are not allowed in the Federal Republic of Germany, may be situated: (a) to take advantage of natural groundwater discharge zones, to afford a measure of control and protection against leachate migrating in undefined directions; and (b) to take maximum advantage of natural attenuation capabilities of soils, providing that an acceptable minimum required migration distance and/or time can be pre-determined with confidence (otherwise, contingency planning may be necessary)
- "controlled release" sites may be underlain by a special permeable lining material to afford the leachate a degree of treatment as it passes through the lining material into subsurface soils
- wastes may be processed prior to disposal to improve handling of the waste or to render the potentially leachable constituents relatively immobile through chemical fixation or encapsulation processes
- leachate treatment by biological and/or physical/chemical processes, alone or in combination, may be feasible with a possibility of subsequent land disposal of the leachate by spray irrigation in areas where contamination by heavy metals can perhaps be tolerated
- leachate recirculation through the landfill may be a process which can be successfully used in conjunction with a treatment system, with a possibility that landfill leachate recirculation at co-disposal sites may enhance metal tie-up in fills through formation of sulphides

- landfills may be operated to minimize infiltration of water into the landfill by the use of: impermeable cover material; recultivation to enhance evapotranspiration; or, final cover grading and slope maintenance procedures
- many other site specific alternatives regarding site operation to be considered once siting, design and construction alternatives have been considered
- long-term concerns such as perpetual care liability and possible accidents need to be taken into account.

3.5 Regulation and Guideline Development Potential

3.5.1 Areas which may be regulated, are (with reference to Figure 1) siting, final site use, and the control of material flows to ensure acceptable disposal and minimum environmental impact, and could include regulations restricting or prohibiting:

- co-disposal
- waste material types going to landfills
- total loadings of specific materials going to landfills
- areas to be landfilled
- operational and access aspects
- infiltration of precipitation, snow melt, surface run-off, and recirculated leachate into the landfill
- leachate discharges from landfills into surrounding environments (soils, surface streams, etc.)
- discharge of treated leachate to municipal sewers
- discharge of treated leachate to receiving water in excess of water standards
- discharge of leachate treatment sludges to land
- gas migration from landfills through adjacent soils
- gas utilisation as a fuel.

3.5.2 Areas or activities for which guidelines may be developed could include:

- landfilling (waste handling and deposition)
- leachate collection
- leachate treatment
- leachate recirculation
- gas control
- landfill lining
- surface sealing

- landfill surface recultivation
- waste encapsulation or chemical fixation
- (test procedures) for wastes
- surface and/or groundwater monitoring (sampling/testing procedures)
- waste processing
- leachate spray irrigation (in special cases).

3.5.3 For practical reasons the participants decided to present their findings/studies under the following heading:

- Co-disposal
- Leachate Production, Migration, Attenuation and Treatment
- isolation
- immobilisation
- alternate disposal operations
- long-term behaviour assessments
- associated studies.

4 LANDFILL RESEARCH

4.1 Co-disposal

Following the areas of concern identified in 3.5.3, this Section deals with the actual findings, i.e. with the studies submitted by the participating countries in the fields of co-disposal, leachate, isolation, immobilisation, alternate disposal, long-term assessment, and associated studies.

4.1.1 General. Co-disposal studies deal with the interactions between municipal solid wastes, and/or other wastes, with hazardous wastes and also attempt to identify which wastes can be co-disposed, and in what quantities, to ensure minimum environmental impact.

4.1.2 United Kingdom. Co-disposal studies have been or are being carried out on the following wastes: heavy metal hydroxides, arsenic wastes, acid pickling liquor wastes, cyanides, phenolic wastes, oil/water emulsions, spent-oxide gasworks wastes and pesticides. More specifically, large-scale test cells are being used for co-disposal experiments in the case of acid pickling liquor wastes, pesticide wastes, spent oxide gasworks wastes and phenolic lime sludges. In the case of acids and pesticides column experiments are also being conducted. Drum-scale experiments are being carried out on oil/water emulsions, and 10-litre jar tests and leachate shake tests on arsenic wastes viz arsenic trisulphide, soda-ash waste from lead smelting, copper/chrome/arsenic treated wood ash arsonopyrite-bearing mine spoil.

Although a repetitive shaker test for hazardous wastes is being developed, the limitations are obvious taking into account the heterogeneous nature of wastes.

4.1.3 Netherlands. The following research activities are currently underway in the Netherlands:

(a) Chemical and biological mechanisms in a landfill site in the case of codisposal.
(b) Field test cells with contaminated packing wastes from paint industry with MSW
(c) Column studies on the interaction between MSW and dry batteries.
(d) Study on nitrogen-containing compounds in leachates from sanitary landfills.

In case of co-disposal more knowledge is required about the interaction between a waste and a sanitary landfill leachate. For practical reasons a standard leachate has been adopted to study this interaction. The composition of this standard leachate is based on

the most common parameters of an "average" natural leachate, like pH, COD, kjeldahl nitrogen, salt content and organic acids and therefore may consist of lower carboxylic acids like acetic acid, ammonium chloride and inorganic salts like potassium sulphate. In this mixture the organic acids and ammonium salt do not only serve as pH determining agents but also act as complex formers, although very weakly.

Conclusion

1. Leachates from sanitary landfills contain free and bound amino acids (peptides) in a concentration, ranging from 200 to 1000 mg/l, calculated as glycine.
   The concentration of amines is very small compared with the amino acid concentration and therefore will be neglected.
2. The "average" content of amino acids in leachates from sanitary landfills amounts up to about 500 mg/l glycine equivalents.

4.1.4 **Federal Republic of Germany.** Co-disposal studies and findings were summarized as follows in a contribution document dated April 79.

The decision to permit co-disposal of wastes with municipal wastes or disposal at a special chemical landfill is essentially based on the evaluation of the biological, chemical and physical reactions of the wastes already landfilled with the wastes to be disposed of and on the prediction regarding leachate and landfill gas emissions. At present it is possible to supply this information only very incompletely due to lack of scientific knowledge on the subject. Even description of the wastes presents problems, because waste examination methods are not yet adequately developed or standardized.

The difficulties in examining waste lie in collection of samples, solubilization of samples and in analysis of the eluates. In particular, evaluation of the eluate analysis is difficult and controversial, because the eluting procedures used today do not provide reproducible and transferable results and the test conditions do not closely simulate the processes in the landfill body. This follows from R+D projects FE 103 05 019/02 UBA/BMI and 103 02 211/01 UBA/BMI, in which leaching tests were critically evaluated resp. an analysis of the problem regarding co-disposal of household refuse with wastes from various other sources was carried out. It was made clear in the analysis of the problem that predicting the long-term behaviour of the wastes landfilled and thus also of the emissions is, at present, not possible, because the physical, chemical and biological processes in the body of landfills have till now been able to be only insufficiently described.

4.1.5 **U.S.A.** The US EPA research program is not specially directed to substantiate the environmental acceptability of co-disposal of hazardous wastes with municipal refuse. The Agency has chosen not to implement a comprehensive leachate and gas release characterization program, particularly with respect to co-disposal, because of the many different wastes (hazardous, municipal, industrial, etc.), which could be placed in a land disposal facility. The anticipated scope of such a program is greater than the Agency's resources could support and the results would be available to regulatory officials and the regulated community only several years after the start of experimentation, nearly ten years later if field validation were desired. The Agency's intent is to provide greater control of those wastes which present greater threats to the environment and human health. Thus a regulatory program was developed which allows the owner/operator and the regulatory official to design, evaluate, and modify (when monitoring indicates a need) the land disposal of specific wastes or combination of wastes. Such a regulatory approach does not prevent the co-disposal of hazardous wastes with municipal refuse. It does require however, that the applicant demonstrate through literature reference or experimentation that the wastes to be disposed at the proposed facility do not present a short or long term hazard. The responsibility for research is therefore the applicant's; the permit official acts only as a critical reviewer of the proposed facility. Realistically, it is expected that the cost of documenting the absence of a hazard will result in unit costs (cost/unit volume of landfill) that would not be competitive with municipal landfill unit volume costs.

The regulatory definition of hazardous waste allows for small quantity exclusions; the disposal of these small quantities are, however, required to comply with the criteria for non-hazardous waste disposal. (ie. municipal wastes) A potential problem is presented if many samll volume hazardous wastes are disposed at a non-hazardous waste landfill. There is limited information available to establish definitive and supportable guidance on how small volume hazardous wastes can be safely disposed at such facilities.

Several experiments are under way to evaluate the Extraction Procedure (EP) which is used by the waste generator to determine if a waste is hazardous. The EP is intended to yiedl liquid mobilized contaminants under conditions similar to those at a municipal refuse landfill. Thus the EP may be loosely construed to be a procedure which yields liquid borne contaminants which may be expected if the waste was codisposed with municipal refuse.

Consequently the Agency's research program is developing procedures techniques, and guidance materials for use in evaluating hazardous waste land disposal facilities. No specific co-disposal research is underway, however, related information is being obtained under a program to evaluate the Extraction Procedure.

4.2 Leachate Production, Migration, Attenuation and Treatment

4.2.1 General. These are studies concerned with the leaching of wastes, and the migration of the leachate through saturated and unsaturated soils under the influence of natural attenuation mechanisms in the soil.

4.2.2 United Kingdom. The main areas of research representing Phase II of the programme of hazardous wastes in landfill sites have the following objectives:

(i) To elucidate the mechanisms controlling the generation and movement of leachates and their attenuation in the unsaturated and saturated zones beneath and adjacent to landfill sites.

(ii) To determine the microbiological processes in various zones within the landfill, at the interface at the base of the landfill and in the unsaturated zone.

(iii) To determine the properties of aquifers including dispersion and dilution of the pollution plumes.

(iv) To evaluate the techniques for the landfill disposal of industrial waste as a co-disposal option with municipal waste.

(v) To evaluate the attenuation properties of permeable lining materials in order to introduce an artificial attenuation zone.

A substantial amount of information has been obtained from the detailed studies of the interaction of leachates with various unsaturated zone strata and the behaviour of pollution plumes in the saturated zone. A considerable amount of data remains to be analysed and experimental work is continuing. It is hoped that quantitative guidelines can be formulated in terms of landfill site loading of heavy metals in relation to the attenuating and release capacity of particular unsaturated zones.

In broad terms, the following work is in progress:

(i) the use of tritium tracers to determine the migration patterns of interstitial water;

(ii) study of the migration of gas and leachate through the unsaturated zone beneath a full-scale municipal landfill site;

(iii) field monitoring of the saturated zones at four sites to determine variations in groundwater quality with time and relating these changes to local hydrogeological and landfill conditions;

(iv) desorption by artifical leachate of heavy metals attenuated within the rock cores taken from the decommissioned Lower Greensand lysimeter. Similar work is continuing in other isolated rock cores; and

(v) examination of the microbial populations within and below landfills.

4.2.3 U.S.A.

(a) Containment Migration and Attenuation

It is generally accepted that passage of hazardous waste leachates through soils and earth materials decreases the concentrations of solutes in the leachates and limits the movement of pollution from disposal facilities. Physical processes (such as diffusion and dispension), physical-chemical processes (such as adsorption, ion exchange, and precipitation), and microbiological degradation processes that control movement and retention of pollutants have been identified.

The number of these processes involved and their significance at a specific disposal facility depends on the pollutant, the climate, the physical and chemical characteristics of the soil and the waste or wastes, and the design and operation of the disposal facility.

Because the processes do not operate independently of one another, understanding the causes of pollutant movement/retention in a specific situation is difficult. Heterogenity of soil characteristics and the usual lack of knowledge about the types and composition of wastes at a disposal facility are further complications. Consequently, it is difficult to use soil and waste characteristics to predict pollutant movement/retention in soils at hazardous waste disposal facilities with sufficient precision and accuracy to include the action of the soil or earth material as a reliable part of the design for the facility. In the near future (5 years) disposal facility designs will use underlying soils and earth materials to retard liquid flow; their capacity to retard movement of pollutants will likely be used as a safety factor rather than as part of the primary facility design.

Progress has been made in using soil and waste characteristics to predict movement of pollutants in soil but the resulting predictive procedure have not been field tested enough to be the sole basis for regulation of a disposal facility. Because of the

state of development of the procedures careful monitoring of disposal facilities will be required as a basis for adjusting the initial predictions.

Work is in progress on empirical predictive techniques using samples of wastes and soils from the location of interest. This approach appears to be the most promising way to integrate the effect of waste and soil characteristics on pollutant retention processes. The precision and accuracy that will be achieved by this method remains to be determined.

(b) Leachate Treatment

Leachate treatment schemes include biological, physical, and chemical processes; the combination of processes and specific modification will be greatly influenced by the characteristics of the leachates produced. Similarities are expected to exist between the treatment processes selected for leachates from co-disposal and leachates from strictly municipal refuse. The leachate characteristics from co-disposal facilities particularly where the quantity of hazardous waste is small may be expected to be very similar to municipal refuse leachate. Consequently, completed studies on municiapl leachate treatment should be pertinent and useful in selecting the appropriate treatment schemes. Composition of leachates from strictly hazardous waste facilities may not be as strongly influenced by or susceptible to microbial activity as for co-disposal or municipal facilities. Consequently, different treatment trains and schemes may be envisioned, conclusions and recommendations from the previously cited concentration technology project should be particularly useful in this regard.

It is essential, regardless of the nature of disposal (co-disposal or strictly hazardous), that leachate production be adequately assessed in terms of quality and volumetric production rates so that appropriate formulation of unit processes can be made and modifications or substitutions to the treatment processes be made in response to changes in leachate characteristics.

4.2.4 Federal Republic of Germany. The document submitted in April 79, mentions that emissions of leachate and gas, which basically always occur in landfilling with wastes, must be reduced or controlled using suitable construction measures, particularly in the case of hazardous wastes, unless the site selection factors of the landfill (e.g. no groundwater, no residance areas) does permit such emissions.

Of prime importance are construction measures for leachate control.

a) Isolation against leachate

The ground water impact due to leachate has been studied in R+D projects from 1964 to 1973, the results of which were introduced in Phase I of the NATO-CCMS study for the subproject "Landfill".

The result was that

- substantial leachate plumes were detected in the groundwater, in particular when the wastes were dumped into the ground-water and that
- retaining and diluting procedures result in an attenuation of pollution in the soil and in the groundwater.

Since that time landfilling into ground water is prohibited. Many municipal refuse landfills and all special chemical landfills, as far as is necessary, are sealed at their bottom, because of the fact that it has not been possible to simulate the attenuation processes in the soil and ground water or to make predictions and because in most cases there is reason to be concerned about groundwater impact from dumped waste.

b) Collection and treatment of leachate

Tests on leachate showed that leachates from wastes situated in water are particularly heavily polluted (FE 103 02 205 UBA/BMI). Therefore, proper drainage of the leachate from the lined landfill bottom, especially important for landfills in pits, is of great significance. The design of leachate collection pipes and leachate pipes and leachate control wells in many respects fails to meet present requirements.

R+D-project 103 02 205 UBA/BMI has been a research study measuring regularly leachate amount and leachate quality at 9 landfill sizes. After evaluation of the results of the study basic information for designing facilities for leachate collection and leachate treatment will be available.

Leachate is predominantly treated together with municipal resp. industrial waste water. Problems with odor emissions occur from leachate sewers or leachate storing ponds on landfills sites.

The purification of leachate in a special clarification plant (oxidation pond) at the landfill has been studied in an R+D project (MELF-Ndsa) at the Venneberg landfill. After purification the leachate (BOD_5 < 50 mg/l) is nearly odorless and can be sprayed. Possibilities for physical/chemical purification of leachate are being researched too (MELF-NW), because high concentrations of chemical residues remain in the effluent

when using biological purification alone, which may result in impact on waters. Results of the project are not yet available.

c) Landfill gas control

Accidents at landfills, endagerment of structures and damage to vegetation at landfills and in the area around the landfill site have shifted the problem of "landfill gas" into view. Measures to avert hazards have been employed in individual cases (see UBA Materials 7/78). Safety criteria regarding structural units with respect to the hazard from landfill gas are being prepared at this time (FE 103 02 102 UBA/BMI).

Information regarding structural design and efficiency of constructed gas control systems (extractable gas quantity, range of effect) is anticipated from the R+D project FE 103 02 207, in which subsequent gas control by exhausting the gas via probes and gas control via gas wells 1 m in diameter during the course of landfill operation are being studied at a large-scale landfill.

4.2.5 France. In 1975, the French ministry of the environment and the quality of life began a research program on landfilling of industrial wastes. As of July 79 the following eleven studies have been carried out.

1. A methodological study of the interaction between industrial wastes and the environment -- practical application to four types of landfills in the Artois-Picardy region:
   - acid tars; wastes from metal-finishing plants; coal tars; tars containing phenols, sulfides, or cyanides; resins used in manufacturing textiles sandpaper (Centre d'Études et Recherches des Charbonnages de France -Research Centre of the nationalized French coal-mining industry).
2. A study of the hydrodynamic and chemical behaviour of mine tailings in a land disposal site (Bureau de Recherches Géologiques et Minières - bureau for research on geology and mining).
3. A Study of the interaction of wastes from the titanium and electro-chemical industries deposited in the same landfill -- application to the Ochsenfeld disposal site (Bureau de Recherches Géologiques et Minières - see 2 above).
4. A study of the environmental impact of an industrial-sludge landfill at Laimont, France, the wastes consisting mainly of sludge from metal-finishing processes (Bureau de Recherches Géologiques et Minières - see 2 above).

5. A study of the stabilization conditions of cyanide wastes (Ecole Nationale Supérieure de Géologie appliquée et de Prospection Minière de Nancy -national institute for studies in applied geology and mine prospecting, in Nancy, France).
6. A study of leaching processes in a landfill containing homogeneous industrial wastes:
   - a qualitative and quantitative study of leachate from experimental cells filled with wastes (Institut de Recherches Hydrologiques de Nancy -hydrological research institute in Nancy, France).
7. Landfilling of industrial wastes: integrating landfill studies with regional waste-management planning (Université de Technologie de Compiègne-Compiègne university of technology).
8. A study of a process for preventing the dissemination of heavy metals into the sub-soil of industrial-waste landfills (Commissariat à l'Energie Atomique-atomic energy, commission).
9. The use of accelerated leaching tests to predict the chemical stability of industrial sludges--development of the leaching tests (Institut de Recherches Hydrologiques - see 6 above).
10. Development of methods for monitoring changes in and effects of solid-waste disposal sites; study of the toxicity of the leachate from the wastes (Institut National de Recherche Chimique Appliquée - national institute for research in applied chemistry).
11. Methods guide for environmental-impact studies of sanitary landfills for industrial wastes (Seri-Renault Engineering); a copy of this guide is enclosed.

The purpose of the first five studies was to determine how various types of industrial wastes behave when landfilled and what impact they have on the environment. The second five studies were attempts to deal with problems specific to the landfilling of industrial wastes.

In addition, two experimental studies were undertaken at the following landfill sites to determine and monitor the impact of specific industrial wastes.

1) Disposal in experimental containers of the following wastes at the MENNEVILLE (impermeable) landfill site:
   -- acid tars
   -- hydrocarbon sludges
   -- redistillation sludges

2) Disposal in experimental containers of the following wastes at the ORLEANS (semi-permeable) landfill site:

-- acid tars

-- hydrocarbons

4.2.6 Canada. One should keep in mind that in Canada, municipal and industrial solid waste management, including land disposal, is generally a private sector or local government responsibility carried out under enabling Provincial Government legislation and regulation. The Federal government's role is principally to develop solid waste management information, and to develop new or improved guidelines or codes of good practice relating to various waste management aspects. These activities are conducted on a national basis as a service and as a back-up to the public and to the regulatory agencies.

a) Monitoring and Modelling Studies

Five landfills in southern Ontario were the subject of a special in-depth investigation of both the magnitude of contaminant loadings to receiving streams and the contaminant attenuation afforded by the soils at the landfills.

The landfill sites vary in size from 6 acres to 78 acres (2.4 to 31.6 hectares) and contain from 6 million to 150 million cubic feet (0.17 to 4.3 million cubic meters) of waste. Several of the landfills have received a large variety of domestic, commerical and liquid industrial wastes.

For each of the five sites, the contractor prepared a complete description of the site; provided instrumentation and sampling to examine groundwater contamination; collected groundwater and soils data; and, prepared summary reports. Laboratory water quality analysis work was performed by Environment Canada.

b) Leachate Plume Migration and Attenuation

A much more in-depth study of leachate migration and attenuation was initiated at the C.F.B. Camp Borden landfill, which is situated within a simple hydro geological setting. Such an almost ideal, simple setting was thought to be conducive to testing new approaches and techniques, and also thought to offer an opportunity to apply and evaluate numerical plume migration simulation methods.

c) PCB Attenuation in Soils

A modification of the dispersed soil batch reactor procedure is being currently utilized in a study of the attenuation of Aroclor 1016 and Aroclor 1245 in soils. The soils vary in clay content, pH, cation exchange capacity, and organic matter content.

This study is designed to provide some basic information on the behavior of PCB's in soil under anaerobic conditions.

d) Leachate Treatment Projects

The following studies were completed by the

Environmental Engineering Group

Department of Civil Engineering

University of British Columbia

1. "Two-Stage Treatment of a Landfill Leachate: Aerobic Biostabilization With Lime - Magnesium Polishing" - P.T. Wong & D.S. Mavinic (Report completed, June 1980)

2. "Nutrient Requirements for Biostabilization of a Landfill Leachate" -P.E. Temoin & D.S. Mavinic (Report in progress, Sept. 1980)

3. "Biological Chemical Treatment of Leachate" - D.W. Graham & D.S. Mavinic (Report in progres, Sept. 1980)

4. "Effects of Temperature on Two-Stage Biostabilization of Landfill Leachate" - R. Zapf-Gilje & D.S. Mavinic (Reported completed, October 1979)

5. "Physical-Chemical Treatment and Disinfection of a Landfill Leachate" - V.B. Bjorkman & D.S. Mavinic (Report completed, May 1979)

6. "Treatment of a Municipal Landfill Leachate" - C.J. Lee & R.D. Cameron (Report completed, January 1979)

7. "Aerobic Biostabilization of a High-Strength Landfill Leachate" - V.C. Uloth & D.S. Mavinic (Report completed, February 1976)

8. "Treatment of a Low-Strength Landfill Leachate With Peat" - J.R. Corbett & R.D. Cameron (Report completed, April 1975)

9. "Treatment of a Sanitary Landfill Leachates With Peat" - T.R. Lidkea & R.D. Cameron (Report completed, Sept. 1974)

10. "Treatability of Leachate from a Sanitary Landfill by Anaerobic Digestion" - B.L. Poorman & R.D. Cameron (Report completed, April 1974)

(Note: In addition to the above, there have also been several internal and informal, corallary studies on leachate treatment, such as recycling, activated-carbon polishing, etc.)

4.3 Isolation

4.3.1 General. Basically an area which deals with techniques designed to insulate waste from the environment (surface sealing), and the environment from the wasste (bottom lining); i.e. more specifically with:

a) studies concerning the lining of waste disposal sites to isolate such sites from the environment with impermeable materials

b) studies concerning the lining of waste disposal sites permeable materials which effectively attenuate leachate contaminants.

4.3.2 United Kingdom. Permeable liner study to evaluate the movement and attenuation of heavy metal/carboxylic acid leachate through a variety of readily available granular waste materials. Columns containing pulverized fuel ash, limestone quarry waste, china clay, sand waste and spent foundry sand (without phenolic resin binders) have been set up and irrigation recently (November 1979) commenced. The results obtained so far are encouraging with respect to: limestone quarry waste, lagooned pulverized fuel ash and foundry sand.

4.3.3 USA.

(a) Waste Isolation - Liners

The use of liner materials in landfills and surface impoundments can be justified based on a data base that takes into account the following factors:

(1) Liner material - Natural and admixed materials (specifications) have remained the same and are expected to remain the same in the future. With flexible membrane liners (FMC) manufacturers are constantly upgrading formulations to withstand chemical, physical and biological attack. Based on actual physical and exposure data and correlating this with new physical data it can be said that FMC should have a service life of at least 25 years and can be expected to last 50 years. If properly matched (chemically resistant), properly installed maintained life expectations on the order of 75-100 years are not unreasonable.

(2) Composition of Waste Streams - As pointed out, the composition of the waste may reduce the service life. However, if the waste streams do not change life expectations in (1) can be realized.

(3) New Materials - New materials are constantly being developed to contain modern waste streams. We have developed a series of tests that will produce results for

predicting service life. If these results are correlated with existing service life, data expectations on total liner life can be projected.

(4) Waste/Liner Matrix - US EPA has developed 52 month exposure data for selected wastes and liner materials. This coupled with longer (25 years) field data for other liquids can be used for predicting overall service life.

(5) Physical Placement of Liner Materials - Studies have indicated that proper placement procedures of liner materials will enhance the overall chance for longer liner life. While not quantative at this point, preliminary data indicate an improvement in liner performance if these procedures are followed. Ongoing research activites are evaluating the effects to determine if the results will significantly impact the service life.

(b) Waste Isolation - Encapsulation

US EPA has supported research to develop and evaluate unique techniques for encapsulating non-radioactive hazardous waste. Three schemes using polymeric resins have been developed: (1) fusion of resin onto the surface of microencapsulated waste, (2) fusion or spray-on of resin onto a performed encapsulate holding containers of hazardous waste, and (3) overpacking of containers of hazardous waste with welded plastic containers. In Scheme I, powdered high-density polyethylene (HPDE) is fused onto the surface of a matrix consisting of the hazardous waste and polybutadiene. The HPDE forms a seamless jacket around the matrix. In Scheme II, HPDE is fused onto the surface of a performed fiberglass/epoxide receiver for containers of hazardous waste. In Scheme III, a 85-gallon polyethylene (PE) wide mouth receiver is used to overpack corroding 55-gallon drums of hazardous waste. A flat piece of PE is welded to the receiver to form the seamless encapsulate.

The use of polyolefins (primarily high- and medium-density polyethylene), polybutadiene, polyurethane, and fiberglass/epoxides have made it possible to produce encapsulated modules capable of handling different waste forms (dry unconfined wastes, sludges, and containerized wastes). The encapsulation systems are compatible with a wide range of waste compositions and the modules they produce have been shown to have high resistance to chemical and mechanical stresses. They can be expected to provide hazardous waste containment over exceptionally long time periods of longer than 100 years. The nature of the systems is such that they can be tailored to different waste

characteristics and containment objectives. For example, the encapsulated waste can be stored under strict control and removed if required, or be disposed of under various regimes (i.e., landfill, salt mines, storage, etc.).

Results of leaching tests showed excellent retention of the contaminants (including arsenic-bearing salts and hazardous sodium salts) by the encapsulates, even when exposed to harsh chemicals such as 1.5N HCl, NaOH, citric acid, $(NH_4)_2S$, dioxane, NaOH, etc. Tests of resistance to mechanical and physical stresses showed that the encapsulated modules can be expected to withstand such stresses greater than those expected during handling, transportation, and disposal/storage.

Each process discussed is in a different stage of development. The polybutadiene/PE resin fusion system for dry unconfined waste is at the laboratory stage, but a full-scale engineering process and equipment design has been developed. The spray-on system requires additional material R&D to produce structurally acceptable coatings in one application. The plastic weld overpack system is essentially under full-scale development because of its nature. Only limited specimens, however, have been produced. Some additional pilot-scale work is required, followed by a field demonstration of techniques.

Though uncertain, the preliminary economics of these systems appear to be acceptable. If future cost considerations take performance capabilities into account, these systems are expected to become more economically viable.

(c) Surface Sealing

The US EPA has successfully demonstrated the effectiveness of surface sealing technology to reduce the generation of leachate due to surface infiltration. During 1979 an approximate 26 acre site was sealed with a 20-mil PVC membrane. A 15 cm blanket of sand washing was spread over the regrading site, the membrane was then placed over this blanket and covered with a minimum of 46 cm of local sand and gravel. In the seven months since the implementation of the remedial action, the groundwater quality has improved and the leachate plume has retreated to the landfill. Monitoring will continue for a two-year period.

4.3.4 Federal Republic of Germany

(a) Liners

On the subject of liners, the document submitted in April 79, mentions that 42 landfills in the Federal Republic of Germany are lined with membranes made of polymeric

or asphalt materials. In the land of Baden-Wurttemberg only landfill sites with naturally impervious subsoil (clay, loam) are permitted.

There is only insufficient knowledge about the long-term behavior of the naturally impervious subsoil under landfills, but also about the polymeric or asphalt membranes under landfills. In current R+D projects the long-term behavior of lining materials (FE 103 02 203 UBA/BMI) or the behavior of naturally impervious soils is analyzed under the applied load of the landfill and long, constant loading with leachate (FE 103 02 201 UBA/BMI). The effectiveness of native-soil barriers under a low hydraulic gradient, i.e. low water back-up over the liner, was shown in the R+D project FE 103 02 019 UBA/BMI in theory and practice. The permeability coefficient k_f usually determined in laboratory tests does not correspond to the actual value under a low hydraulic gradient, because the relationship between the hydraulic gradient and the flow is not linear, as is often wrongly assumed. A procedure for determining the effective k_f value was developed in the R+D project, which is to be confirmed in series of tests.

The question of the suitability of naturally impervious sites for special chemical landfills is examined in another RD+D project (MELF-NW). The results to date: it can be seen from a literature study on the topic "permeability tests" and from methodical tests for determining the permeability, that reliable, systematic testing and evaluation of sites will only be practical after the development of suitable sampling and testing methods.

b) Impermeable barrier

If impervious layers e.g. clay lie relatively close to the ground surface in the area of a landfill, it is basically possible to seal the landfill subsoil against the stream of ground water with vertical impermeable barriers made of thixotropic liquids (Bentonit), for instance. This measure is to be used, however, more at old dumps than at new landfills due to the large amount of leachate. One impermeable barrier of this type is already constructed at the landfill Geldern, Kleve District, another is about to be constructed, others are planned. As yet there is insufficient experience regarding the actual imperviousness of the barriers and the amount of leachate to be disposed of.

c) Surface sealing

There are at present still no methods suitable for use in reducing the infiltration of rain water in landfills, e.g. by surface sealing or planting with woody plants

and grasses that consume large amounts of water. The possibilities of large-scale tests will be examined in a study (FE 103 02 209/01 UBA/BMI).

d) Landscaping

After filling up portions of the landfill surface, these surfaces must be prepared for later use. The standard method is to incorporate these areas into the landscape and to plant final vegetation on them.

Planting on landfills which have been given a layer of earth from 1 to 2 m as a final cover is not successful from the outset, as examinations of 17 landfills in the R+D project FE 103 02 002 UBA/BMI have shown. In several cases, more than 10 years after the planting of trees and shrubbery into the final cover-material, some of the vegetation was considerably damaged. The damage is partly attributed to dryness as a consequence of poor soil care. The greater part of damages is regarded as result of displacement of the soil air by landfill gas, whereupon black, anaerobic zones in the final cover are referring to. On the other hand plantings made directly in the household refuse showed vigorous growth. The conclusion from the examinations is as follows: if a final cover is required, it must be seen to that the landfill gas cannot penetrate into this layer of soil, but is specifically channeled to gas control points. There are also special problems with uncovered landfills which are not accepted by the public for aesthetic reasons. Furthermore it is argued that the infiltration of precipitation is promoted. Landscaping without covering is therefore viewed with reservation wherever reduction of leachate is at the forefront and wherever hazardous wastes have been disposed of. The mutual influence of water and gas balance in a landfill body resp., various types of the covering and planting techniques will be studied in an R+D project (MELF-NW).

4.4 Immobilization

Basically deals with:

a) studies on techniques for the immobilization of wastes to potentially reduce the leaching characteristics, including chemical fixation and encapsulation

b) studies concerning the behavior or solidified, encapsulated, or other chemically fixed wastes in a landfill

4.4.1 United Kingdom. No experimental work is being carried on behalf of the Department although the research contractors have carried out a confidential evaluation on behalf of the operators, of the two main fixation processes operating in the UK.

However, as a general appraisal of such processes, the long-term durability of leachability of fixed wastes cannot be stated with certainty while in the short-term care should always be taken that the technical capability of the precesses should not be exceeded.

4.4.2 Netherlands

(a) Comparative investigation of four immobilization techniques

This is a laboratory investigation on the chemical aspects of leachability. The report consists of two parts: (SVS/3350)

part I: investigation in the chemical aspects based on the treatment of a synthetic sludge

part II: investigation on an industrial waste (metalhydroxide filtercake) and its immobilised products by column leaching experiments.

The first part of the study, investigation on the chemical aspects, is finalized now. The second part, investigation on the physical aspects i.e. the permeability, will start at the end of 1980. In this first part a synthetic metalhydroxide sludge, containing the metals Hg, As, Cd, Cu and Fe, and its immobilisation products was subjected to several leaching tests. Additionally the immobilised products were analysed by electron microscopy. This investigation of the chemical aspects of leachibility (physical aspects such as permeability, as mentioned above, were not included) leads to the conclusion that the four investigated immobilisation techniques do not or hardly cause a reduction of the chemical leachability of the immobilised synthetic sludge.

4.4.3 USA

(a) Waste Immobilization

Chemical stabilization methods now available or being developed have as their goal the safe ultimate disposal of hazardous waste either by a productive way or by landfilling. Ultimate disposal implies the final disposition of persistent, non-degradable, cumulative and/or harmful waste. Four goals attempting to be met are:

(1) improve handling and physical characteristics
(2) decrease surface area across which transfer or loss of contained pollutants can occur
(3) limit solubility of any pollutant contained in the waste
(4) detoxity contained pollutants.

These goals can be met in a variety of ways but not all techniques (processors) attempt to meet all these goals.

The existing data base (limited) can predict the fate of fixated material with regards to the above goals. Using this base of information it is possible to extend into other inorganic waste streams and other disposal situations which minimize the environmental impact.

Organic waste streams continue to present problems for the technology. Processors are expanding their research to include selected organics and attempting to define their limits of use.

No system is applicable to every waste in all situations. The amount and character of the material to be fixed, the economics and the disposal site specific conditions are important factors in deciding which process to utilize under the above mentioned constraints.

4.5 Alternate Disposal Operations

4.5.1 General. This deals with:

a) studies on methods of discharging hazardous wastes onto land other than in a landfill, (that is, other than at a co-disposal or "special chemical" fill site)

b) studies on special procedures for land disposal.

4.5.2 United Kingdom. From the UK point of view, the following should be stated:

Under UK legislation, except in certain prescribed cases, "a person shall not deposit controlled waste on any land or cause or knowingly permit controlled waste to be deposited on any land unless the land on which the waste is deposited is accepted by the holder of a waste disposal licence specifying conditions".

4.5.3 USA

(a) Alternate Disposal - Land Treatment

The US EPA program includes research and evaluation of spreading (or incorporating) of industrial hazardous waste onto the land for treatment by biological, chemical, and physical processes resulting from interactions of the soil (and its constituents) with the waste. The technology is referred to as "land treatment." The land treatment research program has three basic objectives. These are to:

(1) determine environmental effects from hazardous waste land treatment facilities and their monitoring requirements,

(2) determine hazardous waste land treatment facility closure requirements and post-closure monitoring requirements, and

(3) develop basic knowledge required to fully understand land treatment of hazardous waste.

Although selected petroleum wastes have been land treated for over 25 years with no apparent environmental problems, a lack of data and understanding of the operations and monitoring techniques does not permit verification. Also results of limited field evaluations of 6 different industrial waste, (i.e., organic chemical sludge, sludge from plastic industry, air pollution scrubber sludge from leather tanning, petroleum sludge, pickling liquor from metal finishing, and an API separator bottoms sludge) indicated that:

(1) Land treatment can be used to treat selected hazardous waste in an environmentally acceptable manner and,

(2) Confirmed that more research and evaluation is required to fully understand the technology and assure that environmental effects are properly managed.

Environmental problem areas are seen to be related to build-up of immobilized heavy metals in upper layers of the soil, breakthrough of soluble pollutants, uptake of pollutants by plants, survival and breakthrough of pathogenic organisms, and associated areas. Adverse environmental effects may emerge through 4 major mechanisms, i.e., leaching to groundwater, surface runoff, vegetative uptake, and atmospheric dispersion. A complete understanding of these mechanisms is required.

4.5.4 Norway

(a) Sludge-Farming of Oily Sludge.

This study is done by an oil refinery. it is carried out on settled oil sludge from a settling basin. The oil contents in the sludge is 10 per cent, water 25-50 per cent and lead about 3000 ppm of the dry matter. The soil was after one year tested for respiration, oil contents heavy metals contents and microflora.

4.6 Long Term Behaviour Assessments

To avoid taking as reality the results of short-term research especially in the fields of interpretation of leaching tests and long-term impermeability of liner materials, it seems vital to stress the importance of long-term care and of monitoring the behaviour of landfilled wastes.

4.6.1 General. More specifically this means:

a) studies concerning methods for determining long term effects of landfills, including: studies to develop leaching tests for determining leachability of wastes and potential leachate constituents; studies to develop predictive procedures to determine leachate behavior

b) studies concerning long-term landfill behavior and monitoring of long-term landfill impacts.

4.6.2 United Kingdom. Long-term monitoring at "disperse and attenuate" sites has shown that contamination of groundwater responds to seasonal changes in production of leachate and groundwater flow, and is reduced considerably by dispersion in the saturated zone. There has been no evidence of increasing contamination of groundwater with time at the sites investigated. However, the overall variation and absence of any downward trend in contamination indicate that the period of time during which landfill sites produce contaminating leachates is long. Research is being carried out on the development of a leaching test to assess the suitability of a hazardous waste for disposal at a particular site. Work has centred on shaker and column tests using both artificial and real leachate. However, problems are likely to arise in the interpretation of results.

4.6.3 Netherlands

(a) Development of a laboratory leaching test

A Leaching Test (SLT) was developed to determine the contribution of the waste components to the composition of the leachate.

An average synthetic leachate was used so as to obtain comparable results. The following parameters were considered as interesting:

- solubility of its components
- interaction between the waste and the passing leachate.

4.6.4 USA

(a) Study to develop a simulation for predicting the movement of non-conservative solutes in saturated and unsaturated soils.

(b) Field verification of computer simulation for predicting movement of landfill gases in soil.

(c) Field verification of liners, assessment of long-term exposed liner materials from inactive landfills.

(d) Development of techniques and procedures to forecast long term leaching characteristics (volume and composition).

4.6.5 F.R.G.

(a) Establishing recommendations for long-term investigation of landfills, including parameter selection and measurement procedures.

(b) Documenting and critically evaluating leaching tests currently being utilized in the F.R.G. and other countries, with recommendations for a standard leaching test being suggested.

4.6.6 Canada

(a) Developing waste leaching model to serve as a quantitative, descriptive, and predictive model for leachate production with time.

(b) Modelling actual field results to develop predictive methodology for long-term leachate migration behavior.

4.7 Associated Studies

4.7.1 General. This deals with other studies concerning municipal solid wastes only, the results of which can be utilized in our assessment of the behavior of hazardous waste landfills, in co-disposal situations.

4.7.2 U.K.

(a) Managed MSW landfill studies to investigate effects of various deposition and compaction techniques and operating parameters on gas and leachate production.

(b) Monitoring of two disposal MSW sites for gas and leachate production under dry and standing water conditions in the landfill sites.

(c) Studying leachate recirculation to investigate volume reduction effects and changes in leachate composition.

4.7.3 Netherlands

(a) Studied leachate contamination of groundwater, with test fields.

4.7.4 USA

(a) Research on Characterisation/decomposition

This research area is mainly concerned with the behavior of municipal sanitary landfills. Factors affecting gas and leachate production, quantity, and quality are being assessed. Recommendations, based on the data received, are made for the design and operation of disposal sites. Areas for additional research are also identified.

The current US research activities on characterization/decomposition consist of ten specific items. A listing of these items follows. Note that co-disposal is mentioned under item 5.

1 Determine Pathogenicity of MSW Leachate
2 Field Evaluation of Test Cells for Gas and Leachate Production
3 Evaluation of Landfilled Processed Municipal Refuse
4 Evaluation of Landfilled MSW and Industrial Wastes
5 Determine Effect of Moisture Regime on Gas and Leachate Production
6 Summary and Assessment of Leachate Production from Sanitary Lanfills
7 Review of Municipal Sewage Sludge Disposal
8 Field Vewrification of Liners: Assessment of Long-Term Exposed Liner Materials From Inactive Landfills
9 Evaluation and Comparison of the Environmental Impact of Special Types of Landfills
10 Investigations of Factors Involved in Adaptation of Woody Species to Condition of Completed Landfills
11 Assessment of Preplacement and Placemne Procedures Used in Constructing Lined Facilities
12 Liner Materials Exposed to Leachate

4.7.5 Federal Republic of Germany. Several studies concerning municipal solid wastes, were completed or will be completed, in the field of controlled landfill operation, including controlled leachate and gas collection.

Of decisive importance to controlled landfill operation are

- the control of waste being delivered (entrance control)

- the control of wastes to be landfilled (on-site control)
- the techniques for compacting the wastes (compaction techniques).

a) Entrance control

Reliable entrance control is expensive and requires a large staff. Examples of model entrance controls are predominantly at large landfills, where personnel costs and costs for scales and waste examinations do not have a very drastic effect on the specific landfill costs (DM/tonne).

The methods are lacking for fast examination of wastes at the entrance to the landfill, which permit reliable identification of the wastes. Extensive analysis can cause considerable delay of entrance control of deliverers. Therefore waste examinations are often inadequate.

b) On-site control

In addition to the entrance control checking the wastes during unloading at the landfill is necessary in order to determine beyond doubt the identity of the wastes being delivered. Trained personnel, which in most cases is not available, are required for this purpose.

c) Compaction techniques

The influences of simple, fundamental compaction techniques on the decomposition processes in the landfill body, on the water balance and the generation and composition of gas in the landfill and thus on the gas and leachate emissions are largely unknown. The main effort at present is to achieve a high level of inside density in the landfill body, in order to store a large quantity of waste in the landfill and achieve high stability, to permit operation of the landfill under all weather conditions and to avoid accidents.

d) Inside density

In view of the fact that the data mentioned in literature regarding the inside density of wastes achieved in landfill practice are extremely scattered, but since this value is important for landfill planning (operation time of the landfill), for operation of the landfill (checking the plan values) and after closure of the landfill (predicting settlement of the landfill body), seven landfills at which all wastes are weighed will be studied in the R+D project FE 103 02 204 UBA/BMI. The volume of deposited waste is determined by aerial surveying. The values available to date for the inside density lie

between 800 kg/m^3 with approx. 85% household and bulky refuse and 1600 kg/m^3 with 75% inert materials. Other influences such as weight of the steel-wheeled compactors and landfill height were not able to be determined until now. The settling measurements also carried out at these landfills have not yet produced results useable in practice on behalf of the total settlement of the landfill body.

e) Stability

Examinations of the stability of landfills in the case of co-disposal of household refuse and dehydrated sewage sludge (65 - 70% water content) showed that the sludge should not be mixed with solid municipal waste or be compacted in continuous layers, because the stability of the landfills is negatively influenced in this manner (FE 103 02 009 UBA/BMI). According to computer analyses the best method is to dispose of sludge in cells, using solid wastes to aid the stability between the individual pockets of sludge.

4.7.6 Canada

a) Leachate Recirculation

Another west coast landfill, situated on Vancouver Island north of the Greater Victoria area, is under investigation to determine the feasibility of leachate recirculation, over an extended period of time and under annual excess moisture conditions.

A study program was designed specifically to provide data on the effects of leachate recycle onto an existing major landfill. It will produce information which can be used at other sites as well as information specific to the test site. Information will be obtained in the following areas:

a) quantity of leachate emitted by the fill;
b) rate of fill stabilization;
c) disposal of water by evaporation and evapotranspiration; and,
d) use of the fill as a capacitance during peak flows of leachate.

It is recognized that a considerable amount of work has been done elsewhere on the recycling of leachate which has shown that recycling under controlled conditions can accelerate stabilization of landfills and reduce contaminants in the leachate. It has also been found that heavy metals tend to build up in the leachate. The previous results are sufficiently encouraging to consider a full-scale field test on an active sanitary landfill.

b) Septic Tank Sludge Landfilling

The proper disposal of septic tank sludge also remains a problem. The raw sludge is generally not acceptable for discharge into a municipal sewer system, and simple sludge lagooning is also generally unsuitable in many locations. A significant quantity of this waste has been going into landfills, although recent concern about this practice on the effect of landfill leaching has caused many local authorities to disapprove of such practice.

The effect of septic tank sludge additions to municipal refuse was studied at the University of British Columbia, as part of a landfill leaching investigation conducted for the Province of British Columbia. It was shown in this preliminary work that the addition of septic tank sludge to mixed municipal refuse could significantly reduce the concentrations of contaminants in the leachate, under certain conditions.

If these preliminary findings could be confirmed, this would indicate that the discharge of raw sludge at landfills may be an environmentally sound practice. A follow-up study was initiated.

The objective of this study was to identify a range of application rates at which septic tank pumpings can be discharged to a landfill without increasing leachate contaminant loadings to a receiving environment.

There appears to be a ratio of sludge weight to refuse weight above which an improvement of leachate quality will occur, and below which poorer leachate quality results. The determination of such a rate breakpoint would be required for design considerations.

The current lysimeter study is designed to investigate the behavior of varying sludge additions on leachate, under varying conditions of rainfall application and refuse depth.

c) Leachate Toxicity Measurement

A specific procedure being developed is the measurement of leachate toxicity. Toxicity has often been suggested as a valuable indicator parameter in any monitoring of surface waters receiving landfill leachate discharges. However, standard bioassay procedures are expensive and generally require large volumes of effluent, and many take up to three days per sample. A rapid toxicity procedure has been developed to overcome these problems, and it has been demonstrated to be a less expensive, valuable field monitoring procedure.

The procedure, which is called the residual oxygen bioassay or the rapid toxicity assessment, was developed and tested in British Columbia at the Richmond peat bog landfill, utilizing a mobile lab unit inside a van.

All bioassays were conducted with 1.0 - 2.0 g. rainbow trout (Salmo gairdneri Richardson).

5 TECHNICAL CRITERIA FOR LANDFILLS

5.1 General

A number of major problems in the research methodology are not yet solved:

- it is not yet assured that reproducible test results will be obtained, because a suitable waste analysis procedure is not available and it has not yet been possible to reliably describe the landfill conditions, in particular in physical, chemical and biological processes in the landfill body with respect to the wastes and their behaviour with time;
- the test results are not transferable, because reproducible test results could not be obtained and the conditions of transferability of laboratory tests, semi-scale tests and field tests are not definitely known.

Reasons for this are

- the heterogeneous composition of the wastes, in fact of both individual wastes, e.g. acid sludges, hydroxide sludges, plastic wastes, and, in particular, waste mixtures, e.g. household refuse, sewage sluges;
- the subsequent heterogeneity of the landfill body, a problem which is increased as result of regionally different waste accumulation;
- varying landfill marginal conditions such as climate, size of the landfill and landfill operation, which until now were not adequately described or were not able to be in order to obtain reproducible research results.

Therefore, high priority must be given to work on improving research methodology, as for example

- standardization of the examination methods,
- development and application of suitable measuring equipment,
- defined test conditions

but, at the same time, the reaction processes in the landfill body must be researched as well, in order to be able to provide practical test conditions for laboratory tests and semi-scale tests.

As long as the results of simulation techniques are not adaptable, emission measurements at landfills, e.g. leachate and landfill gas for assessment of the particular

situation of a landfill have to be carried out. The long-term behaviour of landfills can at present not be reliably predicted, but only be documentated by continuous measurements.

In order to reduce the costs for measurements, the evaluation of data and for qualified personnel, which cannot be borne by the individual landfill, work must be done to get transferable test or research results.

5.1.1 Areas of research. Following a review/assessment of the findings listed in Section 4, participants either outlined criteria relating to many aspects of landfilling of hazardous waste, or prepared technical suggestions such as manuals, guidelines, codes etc... addressing, sometimes in general terms, such items as:

- contaminant attenuation
- leachate control and treatment
- co-disposal
- waste encapsultion or chemical fixation
- leaching procedures
- monitoring
- modelling
- landfill infiltration
- landfill and landfarming operations
- landfilling specific materials
- landfill liners and cover materials
- gas control

5.1.2 Purpose of recommendations. Please note that the efforts of individual countries, which are listed below, should not necessarily be considered as technical recommendation to others, but rather as a tool which may be useful to the participants in developing their own guidelines, standards, and/or objectives relative to landfilling. Criteria may also be used to develop a general approach to hazardous waste landfilling.

5.2 United States

The USA have, for instance, prepared the following manuals:

1) Management of Hazardous Waste Leachate

The purpose of this manual is to present management options that a permit writer or hazardous waste landfill operator may consider in controlling a leaching problem. Areas of consideration not pertaining directly to leachate treatment, are

presented to inform the reader of possible effects that may need to be taken into account when making a management option selection. Best engineering judgement using all available information is necessary to make the final technology selection.

2) Guide to the Disposal of Chemically Stabilized and Solidified Wastes

The purpose of this manual is to provide guidance on the use of chemical stabilization/solidification techniques for limiting hazards possibly toxic wastes in the environment. Current technology is described as it relates to the improvement in the handling and physical characteristics of the wastes. The decrease in the surface area across which transfer or loss of contained pollutants can occur, the limiting of the solubitily of any pollutants in the wastes and the ability to detoxify the contained pollutants. Physical, chemical and biological requirements and testing procedures are described along with considerations of treatment options. Design considerations for various disposal options and resource recovery alternatives are discussed within the limited data base available.

3) Landfill and Surface Impoundment Performance Evaluation

This manual describes how to use a model to evaluate the degree of control of leachate release provided by a landfill design. The author has taken the likely wide variance in technical backgrounds of his intended audience into account by presenting in full the rigorous mathematics involved in reaching his final equations.

4) Lining of Waste Impoundment and Disposal FAcilities

This document contains descriptions and characteristics of various types of wastes with reference to their polluting or partially polluting components and the effects of these on the various liner materials. The liner materials discussed include remolded and compacted soild and clays, admixes, polymeric membrane liners, sprayed-on liners, soil sealants and chemisorptive liners. The specific characteristics of liner materials in service environments with various wastes with respect to their compatibility with wastes, their permeability to water and waste constituents, failure mechanisms and estimated service lines are discussed. Data and test procedures are presented for screening and selection purposes.

The design and construction of waste facilities with various types of lining materials are discussed with particular emphasis on the installation of flexible membranes and the associated problems.

The document describes the operation management and maintenance of disposal facilities having different liner materials. Historical costs of installing liner materials for various wastes are included as a point of reference. Decision tree logic approaches are described for selecting liner materials for specific sites including preparation and examples of liner materials specifications.

5) Evaluating Cover Systems for Solid and Hazardous Waste

This manual presents a procedure for evaluating closure covers for solid and hazardous wastes. Firs identification of the primary and secondary functions to be served by the cover and establish relative priorities, e.g., impeding water percolation is more important than supporting vegetation, etc. Second, use data on soil properties in terms of the Unified Soil Classification or the U.S. Department of Agriculture systems to rate available soil for effectiveness in the various functions. Third, specify certain design procedures in the disposal operation for circumventing the defencies of the selected cover soil. Placement procedures, such as compaction, will improve the soil for certain functions. Elsewhere, the soil properties favorable for one function are unfavorable for another, e.g., a clayey cover soil impeding water percolating will prevent leakage of decomposition gases that may also be desired. Fourth, where a single soil cannot serve contrasting cover functions, the designer may incorporate features, such as layering, or can resort to the use of special non-soil materials and additives. The four areas are described in 36 steps taking into account available soils, site specific conditions, details of cover design, and post closure maintenance and contingencies.

6) Closure of Hazardous Waste Surface Impoundments

This manual, although perhaps not strictly related to landfilling, describes the methods, tests, and procedures involved in closing a site to minimize potential environmental hazards. It discusses the considerations that have been overlooked in abandoned impoundments that have caused real environmental insults. The techniques involved are pertinent to closing an impoundment either by removing the hazardous wastes or by consolidating the waste on site and securing the site as a landfill. Technical criteria for implementing the closure, specifically those regarding aspects substantially different than a landfill, are also given.

7) Hazardous Waste Land Treatment

This document provides a state-of-the-art text on hazardous waste land treatment. The document comprehensively describes the steps and considerations which are essential for the design and operation of an environmentally soud hazardous waste land treatment (HWLT) facility. Information is provided on the design approach, site selection, characterization of the wastes, and waste streams, the treatment medium, preliminary tests and experiments on waste-soil interactions, facility design and management, monitoring, contingency planning, and site closure considerations.

8) Hydrologic Simulation on Solid Waste Disposal Sites

This document presents an interactive computer program for simulating the hydrologic characteristics of a solid hazardous waste disposal site operation. Using minimal input data from the user, the model will simulate daily, monthly, and annual runoff, depp percolation, temperature, soil-water, and evapotranspiration. The manual provides sufficient information and commands so that an inexperienced user may perform the operaton. The model is designed for conversational use, that is, interaction with the computer is direct and output is received immediately.

5.3 Federal Republic of Germany

The Federal Republic of Germany applies common criteria and recommendations for the separate disposal of hazardous wastes and the co-disposal of hazardous wastes with municipal wastes. As in other countries, co-disposal of industrial waste with MSW is carried out in the Federal Republic of Germany at many landfill sites and especially so since it becomes more and more difficult, because of public opposition, to establish new chemical landfill sites specially designed to accept hazardous waste.

5.3.1 Problems in the disposal of hazardous wastes. Problems in the disposal and co-disposal of hazardous wastes and domestic refuse occur in practice both on the part of the licensing authorities and the landfill operators, because experience and knowledge regarding this complex of topics are at present not yet complete. Of interest in particular is information about the following topics on which research activities in the next few year must be concentrated:

- Suitability of hazardous wastes for co-disposal with domestic refuse (waste selection)
- Construction and operation measures necessary at the landfill

- Landfill behavior and emission predictions (long-term behavior)
- Monitoring and control measures.

Even though there are no specific criteria and recommendations to date in this respect, already existing legal provisions, regulations and guidelines have contributed to the fact that co-disposal of hazardous wastes and domestic refuse is practiced and facilitated in the Federal Republic of Germany.

The strong requirements for separate landfilling of hazardous wastes are also going to be applied more and more for the co-disposal of hazardous and municipal wastes scarcely involves any risks, should, in the national interest, be implemented as soon as possible for co-disposal as well.

5.3.2 Legal provisions, regulations and guidelines. In accordance with § 2, paragraph 2 of the Waste Disposal Act additional requirements are placed on certain hazardous wastes - particularly in the area of control and surveillance. In the meantime, roughly 40 types of waste have been defined in a special ordinance pertaining to the Waste Disposal Act, are subject to specific constraints, and are disposed of to a large extent in special chemical landfills.

In the Domestic Refuse Landfill Monitoring Order of the Land of Baden-Wurttemberg those installation components of landfills are designated and are to be subjected to detailed construction monitoring and an acceptance procedure. These are, in particular, the landfill base and the installation components for collection, monitoring and removal of emissions such as leachate and gas. Stated in addition are the type and extent of monitoring both during operation and after closure of the installation. The operational monitoring to be carried out regularly encompasses the following:

- Deliveries, operating equipment and surroundings,
- Orderly operation,
- Water resources management aspects and
- Landscaped areas.

It can be assumed that monitoring hazardous waste landfills will not be any less intensive than monitoring domestic waste landfills.

According to the draft for a guideline "The orderly disposal of wastes", in addition to solid municipal wastes, a large number of wastes, in particular industrial wastes, can in general be disposed of in domestic refuse landfills. The responsible

authority makes the decision regarding the type and quantity of the wastes to be disposed of, giving special consideration to the following aspects:

a) Location and capacity of the landfill

- site location with respect to water resources management and geologic conditions (receiving stream, subsoil)
- climatic conditions
- availability of cover material
- available landfill volume and expansion potential
- connection to the local and supralocal traffic systems
- equipment and personnel
- control equipment

b) Compaction behavior of wastes

- ability of landfill body to withstand vehicle load
- emissions (odor, dust, noise)
- quantitative proportion with respect to other wastes acting as a buffer
- difficulties during compaction

c) Long-term behavior of wastes in the landfill

- treatment and disposal of leachate
- loading the receiving stream
- chemical reactions and gas generation
- stability of the landfill
- settling of the landfill body
- landscaping the landfill site

The assessment of wastes in accordance with the above-mentioned aspects which are broken down into detail, results in criteria for deciding whether the waste may be disposed in the landfill without special measures or only when observing special conditions and precautions, or whether it must be taken to another waste disposal installation.

Specific Guidelines for procedure in physical and chemical tests in connection with disposal of wastes were published by the Federal Working Group on Waste (Landerarbeitsgemeinschaft Abfall (LAGA)). These guidelines refer, inter alia, to the collection and analysis of water samples, the determination of elutability of solid wastes and sludge with water as well as to the monitoring of water resources management aspects in the area of waste disposal installations. The test parameters, extent of

analyses and frequency are specified for monitoring of ground water and leachate in domestic refuse landfills. The testing program is to be considered nothing more than a rigid test outline and can be restricted in accordance with a provision of the licensing authority or may be appropriately expanded, for instance, in the disposal of hazardous wastes. All test results are to be presented unsolicited to the responsible authorities in each case within 2 months.

The Land of North Rhine-Westphalia has submitted the draft of a guideline for the "Testing and assessment of wastes" according to which, in the future, wastes and, in particular, industrial wastes are to be uniformly tested and assessed. The guidelines sets forth a classification into 5 test groups:

- Test groups A and B (testing and assessment of the original material)
  - A. General data regarding type and description of waste
  - B. Reaction behavior of wastes, routine tests on the original material
- Test groups C, D and E (tests on the eluate and liquid waste)
  - C. Routine tests on the eluate/liquid waste,
    Follow-up tests on the elute/liquid waste
  - D. Individual tests on the eluate/liquid waste
  - E. Specific tests on the eluate/liquid waste.

There are three appendices to this very detailed draft guideline.

An additional guideline, "Asphalt and polymeric membrane liners for land disposal sites" is presently being prepared in the Land of North Rhine-Westphalia. This guideline includes among others, the following sections:

- Technical principles (general requirements on the lining system and structural design)
- Representation of the stressing factors
- Technological possibilities (materials questions and joining techniques)
- Specific requirements on the lining sheets, test procedures and quality control
- Principles of planning and execution of plans
- Questions concerning landfill operation and its potential effects on the lining system
- Monitoring the integrity of the lining
- Principles of installing the lining sheets.

This guideline is intended to be a technical guide for all users. An essential point worth mentioning here is the thickness of the lining sheets. On the basis of recent

findings and developments in the lining of landfills, a minimum thickness of 2.0 mm is deemed in this guideline to be necessary for polymeric membranes. This requirement makes allowance for, among other things, increased reliability with respect to chemical stresses.

5.3.3 Recommendations for disposal of special wastes

a) General principles

In preparing recommendations for the disposal of hazardous wastes and co-disposal of hazardous wastes and municipal wastes, the criteria contained in the present specifications and guidelines are to be considered the standard. The recommendations based on these criteria, briefly outlined in the following, may be considered at present to be the state of the art in the Federal Republic of Germany.

The disposal of hazardous wastes and co-disposal is only permitted at landfills

- which are sealed against the original ground,
- at which the disposal operation is monitored in particular and
- at which the emissions are continuously checked.

Wastes permitted for disposal (positive catalog) and those wastes to be excluded (negative catalog) are determined on the basis of individual tests by the responsible authority.

b) Type of landfill and lining

The following is imperative at landfills used for the co-disposal or hazardous wastes. Naturally impervious subsoil or a landfill liner in conjunction with sufficient drainage and controlled collection or removal of the leachate to waste water purification plants.

The hill-type-landfill appears to be particularly suited to naturally impervious or sealed-off subsoil. With this type of landfill the leachate can flow by gravity to a collection or treatment plant independent of the landfill operation.

In the case of disposal in pits it is to be assumed that the pits will fill up with leachate over the long term following failure or termination of the pumping out process. In such cases, in order to prevent overflow or penetration of leachate into superficial fissured formations, controlled drainage of the leachate by gravity to a treatment plant must be ensured. Failing this, landfills of this type are not to be used. In addition, it must be expected in the case of artifically sealed pit landfills that the lining will be leaking. In order to ensure that in such cases only small quantities of leachate are able to

penetrate into the subsoil, the influx of water from the outside is to be prevented and an effective surface liner provided.

c) **Monitoring**

A requirement for the co-disposal of hazardous wastes and municipal wastes is that the hazardous wastes permitted for disposal on the basis of established test procedures be qualitatively and quantitatively monitored during delivery (entrance control). Operating records are to be prepared continuously both for the entrance control and the location (disposal grid) and type of disposal (disposal specification) at the landfill (disposal control). These records are to be kept in an available and interpretable form for the purpose of checking emission predictions over the long term (approx. 50 to 100 years and longer).

In addition to these operating controls, emission controls are also to be carried out continuously, even beyond the period of operation of the landfill. These controls would primarily involve quantity and composition of the leachate in accordance with specified test procedures and intervals.

5.4 United Kingdom

The role of the United Kingdom's Waste Management Paper series is mentioned here, since the Codes of Practice contained in the publications have been widely used in drawing up landfill site licence conditions. In this series, guidelines on the disposal of the following wastes have been given: pesticides; arsenice-bearing wastes; wastes from the manufacture of pharmaceuticals, toiletries and cosmetics; asbestos; wastes from tanning, leather dressing and fellmongering; wood preserving wastes; halogenated organic wastes; solvent wastes (excluding halogenated hydrocarbons); tarry and distillation wastes and other chemical-based residues; mercury-bearing wastes; halogenated hydrocarbon solvent wastes from cleaning processes; heat-treatment cyanide wastes; mineral oil wastes; and PCBs. It is also restated here that the results of Phase I of the UK programme of research into the behaviour of hazardous wastes in landfills gave indications as to where the work of Phase II should be concentrated in order to further elucidate the attenuation mechanisms within, below and adjacent to landfills and to determine the behaviour of pollution plumes deriving from landfill sites.

It is hoped that sufficient information can be generated to produce quantitative guidelines for landfill site loadings, both in the case of heavy metals in relation to

the attenuating effects of certain types of unsaturated zones, and for the co-disposal where biodegradation plays an important part.

In the UK, within the context of landfill disposal, it is considered that co-disposal of industrial and domestic wastes may have a significant part to play where biodegradation processes are utilized, and also where heavy metal attenuation can occur in the underlying strata. On this basis, the following factors are of particular significance: site selection, landfill management, adequate supervision, monitoring and basic knowledge about waste/waste and soil/waste interactions.

In some cases, landfills can be upgraded in hydrogeologically sensitive areas by the emplacement of permeable liners of appropriate depth to provide for attenuation of leachate pollutants. Where hazardous wastes are contained in an impermeable site, engineering to avoid the production of leachate may be necessary or methods for the treatment or transportation of any leachate generated will need to be considered.

5.5 France

Selecting the best manner in which to dispose of the various types of industrial waste is a current concern among the administrative authorities responsible for the environment in France. Landfilling seems to be a technically and economically acceptable solution for some types of waste, provides certain precautions are taken (choice of site, control of groundwater and surface runoffs, etc...).

An inventory of operational landfill sites for special industrial wastes has been established and a circular has been published on the landfilling of such industrial waste. It will define the cases in which expensive treatments may be avoided, particularly in the field of energy or in areas generating new pollutions (e.g. atmospheric), by means of controlled landfilling; this circular will therefore complement, with respect industrial waste, the proposed provisions for urban residues contained in the circular or March 9, 1973.

This circular proposes a dual classification which makes it possible to clearly distinguish the types of industrial waste discharges:

1) Industrial wastes are schematically classified into two groups:

   -- Ordinary industrial waste, "which may be assimilated to, treated with and under the same conditions as domestic waste".

   -- Special industrial waste, "as defined in the Order of August 19, 1977, taken in application of Section 8 of the Act of July 15, 1975, which may be the source

of particular damage to the environment. Some special wastes may be landfilled subject to a certain number of obligations, particularly with respect to the operating procedures to be imposed, the control of incoming waste and long-term monitoring".

2) Sites may be divided into three classes depending on the permeability properties of the geological layer which constitutes the bottom of the landfill:

-- non-permeable sites "ensure satisfactory containment of wastes and leachates and are capable of receiving industrial wastes including some hazardous wastes".

-- semi-permeable sites "ensure a slow migration of the leachate through a non-saturated zone of sufficient thickness and are capable of receiving industrial wastes which may be assimilated to domestic wastes" (class 2).

-- permeable sites "ensure a rapid migration of the leachate and cannot be used for industrial waste" (class 3).

The circular provides for at least one site per region, in the light of previous initiatives, the need became apparent for a preliminary inventory and listing of currently active landfill sites for special industrial waste.

This inventory does not include domestic waste and ordinary industrial waste landfill sites, although in some regions, in order to make up for the lack of a special waste site, administrative authorities have authorized a few domestic waste landfill operations to receive certain types of special waste. This report was prepared on the basis of information supplied by the Mines Service and presents current data on (1) the existence of special waste landfills and (2) the inventory of disposal sites.

6 FURTHER RESEARCH AREAS

The following areas of future landfill research have been identified by the pilot.

6.1 Research Area 1

Methods for monitoring the long-term behaviour of landfills

The objective of research area 1 is to provide the methods and techniques (the "hand tools") for systematic and comparative monitoring and investigation acceptability of

- wastes for landfilling
- landfilled wastes
- leachate
- landfill gas
- settlements
- other impacts of landfills

as well as to develop appropriate

- data preparation and
- data evaluation.

Users of these research results shall be landfill operators, local authorities and researchers.

6.2 Research Area 2

Description and prediction of landfill behavior

The objective of research area 2 is to describe

- water balance
- gas generation and composition
- physical, chemical and biological processes in the landfill body
- settlement

as dependent on

- the landfill waste and
- operation of the landfill,

in particular, in order to be able to make predictions about

- leachate emissions
- gas emissions and
- the stability of the landfill body

in order to properly design the

- landfill liners
- leachate treatment plants
- landfill gas control systems

and to be able to select appropriate landfilling techniques.

6.3 Research Area 3

Long-term control and landscaping of landfills

The objective of research area 3 is the development of applicable procedures for:

- controlling the emission of leachate by landfill liners, landfill subsoil barriers, landfill surface seals and leachate purification plants;
- control landfill gas emissions with gas barriers in the subsoil and at the landfill surface, and landfill gas control systems;
- controlling the stability of the landfill;
- appropriate landscaping (planting and sowing grass).

6.4 Research Area 4

Optimization of construction and operation of landfills, in particular for disposal of hazardous wastes

The objective of research area 4 is to test construction and operating measures such as are suitable for minimizing the environmental impact at landfills in general, but in particular at landfills where hazardous wastes are being or have been disposed of.

6.5 Points of Emphasis in the Research

The points of emphasis in the research of the next few years could be as follows:

6.5.1 Development of reproducible methods for practical, interpretable examination of waste, so that the wastes, as input, can be adequately described for laboratory and field tests.

6.5.2 Development of methods for observing and assessing the long-term behavior of landfills, in particular the leachate and landfill gas emissions, as well as the stability and the development of vegetation on the landfills; these methods are to be such that transferable test results can be obtained.

6.5.3 Development of methods for testing the long-term behavior of materials and systems for landfill isolation.

6.5.4 Investigating the dependence of the physical, chemical and biological processes in the landfill body on the wastes and the operating conditions, in particular with the objective of being able to describe the long-term changes of the water balance and gas generation and composition and the settling behavior of the landfill body, to be performed in simultaneous laboratory, semi-scale and field tests.

6.5.5 Carrying out and evaluating leachate and landfill gas tests, as well as investigations on settlement tests and predictions of leachate and gas emissions and settlements as the basis for dimensioning and designing

- landfill liners
- landfill subsoil barriers
- landfill surface seals
- leachate purification plants
- gas barriers in the subsoil and on the landfill surface
- landscaping measures.

6.5.6 Tests for long-term control of landfills with special consideration given to the relationships between the landfill liners, subsoil barriers, surface seal attenuation capacity of the subsoil and collection/purification of the leachate.

6.5.7 Development of standardized procedures for laboratory or semi-scale tests to determine and make predictions regarding the long-term landfill behavior of industrial special wastes as well as sludges from the flue gas washing, slag and fly ash from waste incineration plants.

6.5.8 Investigating the long-term behavior of selected landfills and old dumps.

Working on these points of emphasis aims at quantifying and making predictable the long-term emissions of old dumps and landfills for municipal and industrial wastes being operated at present or in planning, as well as providing suitable construction or operating measures for the reduction or prevention of these emissions.

The evaluation of the impacts of emissions

- from old dumps as well as
- new landfills

is of fundamental importance, because dependent on this evaluation is what expenditure is necessary and justified for minimizing the emissions. The decision whether the landfilling of particular wastes is even acceptable ecologically or economically will be dependent upon the evaluation of the emissions.

7 CONCLUSIONS

7.1 Landfilling can be a suitable method for disposal of certain types of hazardous wastes provided proper precautions in the siting, design, operation and post-operational care of the sites are taken to ensure adequate protection of the environment and public health on a long-term basis.

7.2 The results of landfill research can be used in the development of guidelines and codes of practice to promote improvements in the "state of the art" of landfill practice. The landfill pollution problem, however, remains complex and further research is required to improve the basic understanding of the attenuation mechanisms of leachate pollutants within and below landfills, and to develop means of preventing the ingress of water and the treatment of leachate. It will be necessary to develop cost-effective and environmentally sound control and prevention technology particularly for the treatment of leachates, the lining of landfill sites, and minimizing the generation of leachates.

7.3 Most of the landfill research has focussed on conventional inorganic pollutants while research on micro-pollutants such as trace organics has been very limited.

7.4 Research efforts to date have been directed mainly at the technical and scientific aspects of landfill problems while other aspects such as legal liability, site selection criteria, financial considerations for restoration and maintenance during and after active operation have been largely neglected.

7.5 International cooperation and exchange of information has been helpful in improving the understanding and knowledge of the problems associated with landfill operations.

8 RECOMMENDATIONS

8.1 Long-term environmental and health concerns should be thoroughly examined during consideration of landfilling as a technique for disposal of hazardous wastes.

8.2 Further scientific research should be conducted on the environmental impact of landfills as a disposal and co-disposal method for hazardous waste. In particular such research should examine the potential problems with micro pollutants (trace organics) and leachate collection and treatment.

8.3 Legal, economic, social and planning aspects of landfill disposal should be examined to improve the acceptability of the landfilling of hazardous wastes where water pollution problems are unlikely to occur.

8.4 International cooperation and exchange of information should be encouraged and continued to enhance the transfer of knowledge and to promote the development and implementation of sound landfill control and prevention technology.